LAWRENCE LIVERMORE NATIONAL LABORATORY

FY 2018 Annual Report

SCIENCE AND TECHNOLOGY ON A MISSION

ABOUT THE LABORATORY

Lawrence Livermore National Laboratory (LLNL) was founded in 1952 to enhance the security of the United States by advancing nuclear weapons science and technology and ensuring a safe, secure, and effective nuclear deterrent. With a talented and dedicated workforce and world-class research capabilities, the Laboratory strengthens national security with a tradition of science and technology innovation—anticipating, developing, and delivering solutions for the nation's most challenging problems.

The Laboratory is managed by Lawrence Livermore National Security, LLC (LLNS), for the National Nuclear Security Administration (NNSA), a semi-autonomous agency within the U.S. Department of Energy (DOE). LLNS is a limited liability company managed by Bechtel National, Inc.; the University of California; BWXT Government Group, Inc.; and the URS Division of AECOM. Battelle Memorial Institute also participates in LLNS as a teaming subcontractor. Cutting-edge science is enhanced through the expertise of the University of California and its 10 campuses and LLNS' affiliation with the Texas A&M University system.

ABOUT THE COVER

(front) Chemist Carlos Valdez and (back) biologist Alda Celena Carrillo test samples at the Laboratory's Forensic Science Center. The center's scientists analyze chemical, biological, radiological, nuclear, and explosive samples; provide radiological assistance 24/7; and engage in the critical research and development needs of the intelligence community, law enforcement, homeland security, and health professionals.

Lawrence Livermore National Laboratory

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A researcher holds an example of a Livermore Flexible Probe. The probes are designed to record data on the neural activity of animal and human brains in situ.

INSIDE FY 2018

SCIENCE AND TECHNOLOGY ON A MISSION

At Lawrence Livermore National Laboratory (LLNL), we strengthen national security through world-class science, technology, and engineering. In an ever more rapidly changing world, this enduring mission requires informed anticipation, constant innovation, and disciplined delivery for the Department of Energy (DOE) and its National Nuclear Security Administration (NNSA). To quote the Laboratory's founding director, Herbert F. York, our mission calls for "always pushing at the technological extremes."

In another exceptional year, we fully met our programmatic and operational responsibilities, while establishing and extending our leadership in science and technology. This annual report highlights our many contributions in FY 2018 to making the nation—and the world—safer and more secure.

Our primary mission is to underwrite nuclear deterrence by helping ensure the safety, security, and effectiveness of systems in the U.S. nuclear weapons stockpile. We also provide the technology and expertise across the spectrum of weapons of mass destruction to enable high-confidence implementation of arms control, nonproliferation, and other threat reduction measures. We address deterrence more broadly as it intersects evolving threats in space, cyberspace, and missile defense; and we develop solutions for energy and climate security. We also help our nation's leaders to understand new challenges and opportunities in a manner that is technically informed and sound.

But this is not all. When we have unique capabilities to bring to bear, we provide warfighter support; help respond to natural disasters; and contribute to advances in medicine, human health, and basic science that support DOE's overall mission. As just one example, in FY 2018 an advanced LLNL biomedical technology that delivers vaccines and drugs inside the human body was licensed for use in cancer treatment.

As in past years, in FY 2018 we assessed the status of the W87 and W80 warheads and the B-83 gravity bomb. In addition, we are making excellent progress in a life-extension program (LEP) for the W80-4 warhead and restarting work on the W78. Both systems will benefit from updated safety features. Each is more than 30 years old and full of specialty parts that require replacement. Manufacturing processes have to be reinvented to supplant obsolete ones, and new parts must be tested and certified for long service life and for conditions ranging from

((far left) Speaking at a ceremony unveiling the Sierra supercomputer, Laboratory Director William Goldstein presented the machine as "a powerful new tool for NNSA and stockpile stewardship," representing "a new approach to high-performance computing that will enable us to address and answer scientific questions previously beyond our reach." (left) Researchers prepare for an experiment at LLNL's High Explosives Applications Facility in support of the W80-4 LEP.

icy cold to the center of the sun. And they have to be guaranteed to work in a system that cannot be tested and hopefully will never be used. We face and have met unique scientific and engineering challenges in carrying out these activities.

We continue to look beyond our immediate deliverables to anticipate future developments in an increasingly challenging security environment. Our Laboratory is part of the national "hedge" against the possibility that a sudden erosion in our nuclear security environment might require rapid modifications to our forces. We also play a fundamental role in ensuring that the nation has the competitive advantage in advanced technologies with potential military applications. Our robust science and technology base is a national asset, and in and of itself a crucial element of deterrence.

Carrying out our work for stockpile stewardship requires scientific tools and capabilities found nowhere else in the world, and they open new frontiers of scientific research. Our "bleeding edge" high-performance computers essentially allow us to simulate full-scale nuclear testing. Experiments at the National Ignition Facility (NIF) validate high-energy-density physics models.

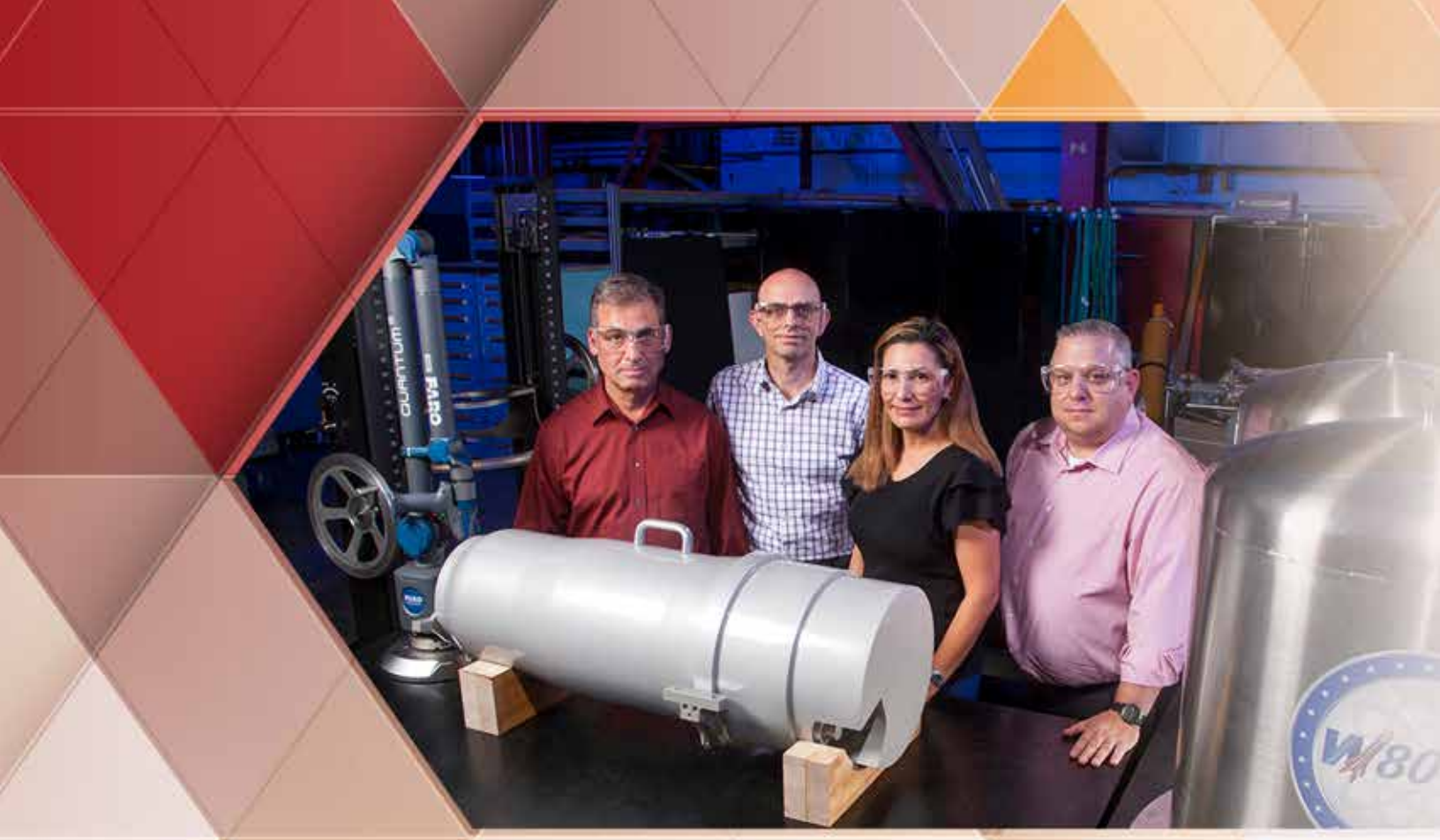
Complementing these flagship centers of excellence are unique capabilities for energetic materials research, radiography, and forensic science, among others.

This year we took delivery of and commissioned Sierra, the world's second most powerful computer. Its workload includes the many classified simulations required for the W80-4 LEP. Sierra supports today's mission needs and sets the stage for future paradigm shifts in computing: The next step, a ten-times faster exascale machine, is scheduled for delivery to LLNL in late 2022. Perhaps more revolutionary is the convergence of supercomputer modeling and machine learning, a phenomenon we call cognitive simulation. This step, already being explored on Sierra, will profoundly benefit our stockpile stewardship mission as well as a host of other scientific problems.

Experiments at NIF provided critical materials property data that informed the evaluation of options for the W80-4 LEP. NIF achieved a record-setting 2.1 megajoules of energy into the target chamber in FY 2018, and other tests continued to help scientists make significant progress toward achieving a burning plasma. Through basic science experiments, carried out by researchers from around the world, NIF has provided a means to study the cores of giant planets, simulated the physics of cosmic accelerators, and explored stellar nucleogenesis under realistic conditions.

The Advanced Manufacturing Laboratory opened in the Livermore Valley Open Campus, furthering the vision of innovation for our national security programs through strengthened collaborations with academic and industrial partners. Livermore is at the forefront in many areas of additive manufacturing, and Laboratory researchers are advancing micro- and nano-technologies for applications ranging from orbiting CubeSats (miniature satellites) for low-cost, high-resolution imaging from low-Earth orbit to biocompatible neural probes for monitoring brain activity.

Finally, our accomplishments this past year, as has always been the case, flowed from a world-class workforce committed to our values of developing new ideas, making a difference, embodying integrity and inclusiveness, and loving the work. By any metric of scientific progress, programmatic impact, or operational excellence, our people continue to set the highest bar.



NUCLEAR DETERRENCE

Ensuring the safety, security, and effectiveness of the enduring stockpile

LLNL's foremost responsibility is to ensure the performance of the nation's nuclear arsenal. The knowledge gained through theory, simulations, and experiments is utilized by weapons experts to assess the condition of stockpile weapons and to develop and certify needed modifications with confidence in the absence of additional nuclear tests.

Annual Stockpile Assessment

In FY 2018, LLNL completed Cycle 23 of the annual stockpile assessment. The process included a formal comprehensive peer review by the nuclear design laboratories (Livermore and Los Alamos) of each other's weapons systems. LLNL scientists continue to enhance the physics and engineering simulation codes that support the annual assessments and certification of weapons. Emphasis is on better scientific understanding and improved predictability and uncertainty quantification. In support of Cycle 23, LLNL completed all assigned milestones for weapons surveillance activities and special studies for the B83, W80, and W87 stockpile systems.

Life Extension of the W80 Warhead

LLNL is partnered with Sandia National Laboratories as the design agencies to develop and certify the W80-4 warhead for the bomber-delivered Long-Range Standoff (LRSO) missile. The Laboratory is making excellent progress in the W80-4 life-extension program (LEP), which entered into Phase 6.2A (design definition and cost study) in October 2017. An important aspect of the LEP is adapting the refurbished warhead to the LRSO missile, which has required close cooperation with the U.S. Air Force and contractors competing for the design of the missile. Working with the NNSA production plants, LLNL developed plans to refurbish aging components and materials in the warheads. The options include employing new manufacturing methods that minimize costs; increase throughput; and reduce the use of materials and processes that adversely affect safety, health, and the environment.

The W80-4 LEP effort requires the full array of NNSA's computational, experimental, and manufacturing capabilities to meet all of the prototyping, proof-of-concept testing, and certification requirements. High-performance computing (HPC) resources at LLNL are used to produce extraordinarily high-resolution simulations that provide an essential computational surrogate for nuclear testing. Wide-ranging experiments at LLNL's National Ignition Facility (NIF), the Contained Firing

(left) LLNL engineers (from left) Tom Horrillo, Bert Jorgensen, Veronica Harwood, and Travis Paladichuk pose with a model of the W80-4. (above) Sierra, the world's second fastest supercomputer, will enable the NNSA laboratories to run higher fidelity, more predictive simulations of nuclear weapons performance and better quantify uncertainties.

Facility, and the High Explosives Applications Facility (HEAF)—and at other NNSA sites—provide data to enhance confidence in computational models used for the W80-4 LEP (see below and p. 6).

Sierra Supercomputer in Operation

In October 2018, NNSA, LLNL, and industry partners officially unveiled Sierra at a dedication ceremony to celebrate completion of this IBM/ NVIDIA supercomputer. Sierra has reached a speed of 94.6 petaflops (quadrillion floating-point operations per second) in a benchmark test, placing it as the world's second fastest supercomputer on the TOP500 List. It serves the NNSA's three nuclear security laboratories in support of the Stockpile Stewardship Program.

This latest machine for the NNSA Advanced Simulation and Computing (ASC) program makes possible higher fidelity, more predictive simulations of weapons performance, and it provides the ability to run large 3D or higher fidelity 2D ensembles of simulations to quantify uncertainties in predictions. Sierra can process crucial 3D simulations up to 10 times faster than prior ASC computers. The machine will be heavily used to develop and certify the W80-4 warhead.

Sierra achieves its enormous speed (a peak performance of 125 petaflops) by using NVIDIA graphics processor units together with IBM central processing units in a heterogeneous architecture. Its arrival represents years of procurement, design, code development, and installation efforts carried out through the CORAL (Collaboration of Oak Ridge, Argonne, and Lawrence Livermore national laboratories) partnership. LLNL has also taken delivery of Lassen, a one-sixth-sized Sierra supercomputer, for unclassified work. DOE's CORAL-2 is underway to procure two exascale (1,000 petaflop) machines. One of them, El Capitan, will be sited at Livermore (see p. 19).

Stockpile Stewardship Experiments

LLNL successfully executed its work in the FY 2018 National Hydrodynamic Test Plan. Experiments supported campaigns to improve understanding of critical weapons science issues, assessments of the current stockpile, stockpile modernization, and programmatic efforts in nonproliferation and counterterrorism. Of particular note, Livermore executed four hydrodynamic tests (two for the W80-4 and others for the B61-12 and the W88 ALT) supporting active NNSA LEPs and weapon alteration programs. The Laboratory also conducted hydrodynamic tests to prepare for fielding subcritical experiments at the Nevada National Security Site that will collect important data about how a plutonium weapon core implodes. Many more experimental activities are underway at HEAF and LLNL's remotely located Site 300 to qualify and remanufacture additional insensitive high explosives to be used in the refurbished W80-4 warheads.

Experiments at the Joint Actinide Shock Physics Experimental Research (JASPER) Facility and NIF (see p. 6) provide essential data about plutonium and other materials at the extreme conditions reached in a nuclear weapon. Experiments at JASPER in FY 2018 collected critically needed data about shock-compressed plutonium.

W80-4 Safety Enhancements
(from the left) Firing tank operator Drew Carlson, electronic technician Raya Yy, and ramrod Shawn Strickland prepare for a test at HEAF. Laboratory experts are undertaking extensive testing and evaluation of a replacement detonator and booster train to initiate the weapon's main charge. In addition to this safety enhancement for the W80-4 LEP, the insensitive high explosive for the main charge has not been made for decades and the Laboratory is developing needed new manufacturing processes.

NATIONAL IGNITION FACILITY

Supporting stockpile stewardship through a wide range of nonignition experiments and pursuit of nuclear fusion ignition, and operating as a national user facility for high-energy-density science

The National Ignition Facility (NIF) team conducted 393 shots in FY 2018. Of these, 256 shots advanced the Stockpile Stewardship Program (SSP) missions of high-energy-density (HED) physics and achieving inertial confinement fusion (ICF) ignition and energy gain. An additional 60 shots served to develop new experimental capabilities for the SSP and calibrate diagnostics. Other shots supported diverse national-security applications and pursued discovery science.

Stockpile Stewardship HED Science Experiments

Campaigns of HED science experiments at NIF explored wide-ranging physical phenomena central to stockpile stewardship. The shots gathered information about the properties of materials at extreme conditions, radiation hydrodynamics and transport, thermonuclear processes, and material mixing. The data are used to improve and validate models of weapons performance. Many experiments jointly addressed challenges arising from the pursuit of ICF ignition and led to a better understanding of physics issues pertinent to stockpile stewardship. Examples include ongoing campaigns examining hydrodynamic instabilities and efforts to determine the strength and equation of state of high-atomic-number (high-Z) materials. In addition, experiments supported the W80-4 life-extension program by providing data to help weapons designers assess options for replacing aged materials in the W80 warhead.

Progress in Pursuing Fusion Ignition

Achieving fusion ignition and energy gain at NIF is a grand scientific challenge. Success will make possible HED science experiments that support future stockpile decisions. Building on successes in 2017–2018 with record-setting neutron yields, scientists conducted focused experiments in FY 2018 directed at design improvements in three key areas to more closely approach the "burning plasma" regime. One area is advanced designs for the hohlraum (the case enclosing the capsule filled with deuterium–tritium fuel). The goal is to create a more symmetric implosion and enable use of larger, more robust fuel capsules. Experiments also explored the trade-off between higher implosion velocity and a resultant greater resistance to compression on overall implosion performance. Finally, other shots studied the degradation in performance caused by the capsule fill tube, which perturbs the implosion.

LLNL scientists are developing advanced machine-learning techniques to improve ICF target designs and uncertainty

(left) A technician prepares four diffraction gratings for installation inside ARC's compressor vessel. The NIF beamlets that enter ARC are stretched out by diffraction gratings, amplified, and compressed back into high-energy, ultrashort laser pulses. (above) In the NIF control room, operators Karl Pletcher and Scott Rogers review the status of diagnostics for an upcoming shot.

NIF Sets New Laser Energy Record

NIF fired a record-setting 2.1 megajoules of energy into the target chamber, achieving a 15 percent improvement over the laser system's design specification. The energy increase enables a wider range of stockpile stewardship experiments and provides a boost to the pursuit of ignition. The achievement is the result of cutting-edge materials science research that has raised the threshold of damage initiation in NIF optics and reduced the cost of mitigating damage when it occurs.

quantification. The team used the Trinity supercomputer, sited at Los Alamos National Laboratory, to develop an enormous database of 60,000 detailed simulations of ICF implosions, varying nine critical design parameters. They used the database to train a machine to reproduce the simulation results at any point in the nine-dimensional space. This learned representation provides the capability to perform exhaustive searches of the design space, millions of times faster than the original simulations were generated. Surprisingly, the team found a new, aspherical ignition target design that is more tolerant of implosion imperfections. They have extended these machine-learning models to include uncertainty quantification tools that are used to gauge confidence in expected implosion performance for design regimes not yet accessed experimentally. These capabilities, developed with ICF as the test bed, are being incorporated into other research areas central stockpile stewardship.

A "Laser within a Laser"

Embedded in NIF, the Advanced Radiographic Capability (ARC) operates as the world's most energetic short-pulse laser. It promises to greatly improve diagnostic capabilities for ICF and stockpile stewardship HED science experiments. ARC has been utilized in more than 60 experiments since it was first commissioned. Using the input of two of NIF's 192 beamlines, ARC can produce four beamlets, each with 1 kilojoule of energy delivered in less than 10 trillionths of a second. These beamlets can then create intense beams of high-energy x rays that are used to radiograph materials being shocked or compressed to extreme densities. The NIF team has successfully demonstrated two backlighting techniques to produce multiple radiographs in a single HED test. One technique works for light elements (for example, the fuel in ICF targets); the other is for high-*Z* materials of importance to stockpile stewardship.

Discovery Science at NIF

In FY 2018, Discovery Science at NIF benefited from exciting opportunities made possible by ARC, which can be used to generate high-energy, high-flux particle beams. In initial experiments, jets of 18 megaelectronvolt (peak energy) protons were produced, which could be used to study the electromagnetic fields generated in HED science experiments. Researchers have also created a matter–antimatter plasma with pairs of positrons and electrons. This achievement opens the door for laboratory experiments to study the most energetic processes in the universe.

In addition, NIF Discover Science researchers studied the state of matter in brown dwarfs (stars that failed to ignite) and the turbulent after-effects of a supernova as the ejected material expands into space. Many other tests focused on collecting vital data to construct improved models of the interior of exoplanets. Through a series of shots at NIF, scientists examined under what conditions fluid hydrogen in giant planets transitions from an insulator to a conductor. The results clearly showed which of two competing models is correct. Other researchers compressed iron to peak pressures of 14 million atmospheres, four times those previously achieved. The data pertain to giant rocky planets, which are abundant among the exoplanets discovered. Experiments also provided data on iron–silicon alloys at similar pressures. Another collaborative team found the first experimental evidence for superionic ice (see p. 14).

GLOBAL SECURITY

Reducing the threat from terrorism and weapons of mass destruction and enhancing global stability

LLNL develops innovative advanced technologies to help the government anticipate, identify, and address global security threats. By applying expertise in chemical, biological, radiological, nuclear, and explosive weapons, our researchers support threat preparedness, prevention, protection, and response and recovery. In addition, Livermore innovations in space situational awareness and cyberdefense help strengthen national security in an increasingly interconnected world.

Deep Learning for Nuclear Nonproliferation Analysis

Laboratory researchers are developing new deep-learning and high-performance computing algorithms that sift through massive amounts of data for evidence of nuclear proliferation activities. The effort, called Advanced Data Analytics for Proliferation Detection (ADAPD), is aimed at accelerating the pace of nonproliferation analysis and scaling it to much larger data sets than humans could search manually. By handling the initial screening, the system makes evaluating evidence of proliferation activities much more manageable for analysts, who are relieved from examining millions of images and hundreds of videos.

ADAPD pushes the limits of deep learning by using neural networks to "map" images, text, and video into a feature space. All relevant data are categorized based on how they relate to the processes involved in building a nuclear weapon. An especially powerful aspect of ADAPD is its ability to find conceptually related data that very often lack key words. To tackle this challenge, the LLNL team developed new "self-supervised" algorithms that enable the neural network to automatically learn what features are important to "see" or "read" for each type of data.

Defending the Nation's Power Grid

An accident or cyberattack on one component of the nation's power grid could create cascading problems for huge segments of the grid. Livermore's Skyfall is a cyber–physical test bed designed to realistically model the grid's behavior by combining high-performance computer simulations with a full-fledged power substation that behaves as if connected to an actual power grid. The computer feeds the substation a set of conditions such as voltages and currents that are identical to signals that would be received in the real world if a system were

(left) Laboratory chemist Audrey Williams, a member of the team that took the OPCW proficiency test, analyzes a reference standard using nuclear magnetic resonance spectroscopy. (above) Program leader Nate Gleason (seated) studies electrical sine waves on a monitor at LLNL's Skyfall test bed facility, while research colleagues Vaibhav Donde (left) and Jovana Helms examine Skyfall's in-house relay substation.

under attack. The researchers watch how the Skyfall substation responds and then extrapolate the results across the wider network. Resulting high-fidelity simulations provide a realistic view of system behavior during an attack from beginning to end—pointing out ways to increase the resiliency of the nation's power grid.

Forensic Scientists Earn an "A"

Despite a worldwide ban, chemical weapons pose a threat to global security. Since 2003 Livermore's Forensic Science Center (FSC) has been one of only two U.S. laboratories (and one of only 20 worldwide) accredited by the Organisation for the Prohibition of Chemical Weapons (OPCW). LLNL earned its eighth consecutive "A" grade in its yearly OPCW proficiency test. This test required identifying six substances hidden in extremely complex chemical matrices. More recently, the Laboratory served as the grader for a test.

The FSC supports chemical, nuclear, and biological counterterrorism activities and also conducts research in new types of forensic methods. For example, FSC scientists developed capabilities to use proteins from bones—as well as hair—for identifying human remains recovered from challenging environments. The advance is a new tool for the forensic science community and a complement to DNA analysis, the gold (but fragile) standard for human identification.

Progress in "Brain-on-a-Chip"

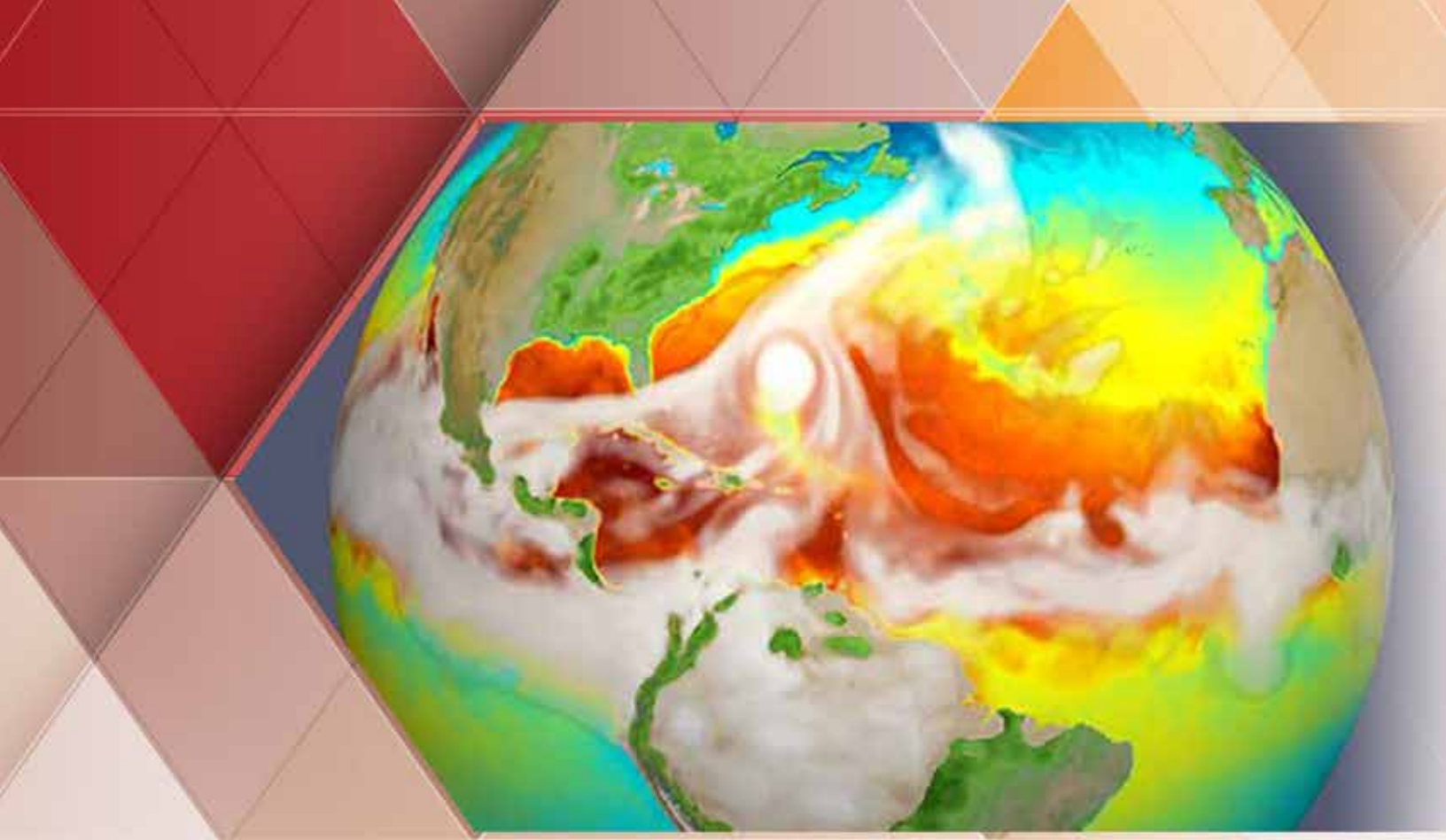
Laboratory researchers have made significant progress in their development of a "brain-on-a-chip." Their goal is to use the technology to test and predict the effects of biological and chemical agents, disease, and pharmaceuticals without the need for human or animal subjects. The device, which is part of Livermore's growing iCHIP (in vitro chip-based human investigational platform) project, simulates the human central nervous system by recording activity from multiple brain cell types grown onto microelectrode arrays. The team successfully performed tests on a chip with four distinct areas, representing three subregions of the brain and the cortex. The researchers were able to observe how the cells interacted over time through bursts of electrical energy.

New Tool for Emergency Planning

A Livermore team developed a planning resource to assist local governments in determining the best actions to take after the detonation of an improvised nuclear device (IND). The web-based IND City Planner Resource (iCPR) provides scientifically based IND effects information for 60 U.S. cities. It leverages LLNL's computer science expertise and the modeling system developed at the National Atmospheric Release Advisory Center (NARAC), which serves as DOE's plume-modeling center for real-time and predictive assessments of nuclear, radiological, chemical, biological, and natural emissions. The interactive system combines geographic information on building types with protection factors developed by NARAC to estimate at the census block level the protection provided by buildings. The iCPR tool also features animations that show how affected urban areas evolve over time from detonation to one year later.

Nanolipoprotein Technology Licensed

An LLNL-developed biomedical technology that can deliver vaccines and drugs inside the human body has been licensed to a company in Michigan. It is to be used for use in cancer treatment. Nanolipoprotein (NLP) particles—water-soluble molecules that resemble the human body's good cholesterol—are used to deliver synthetic peptides that enter the body's lymph nodes and activate T-cells. The activated T-cells then circulate and destroy cancerous tumor cells. Chemist Paul Hoeprich (left) and biologist Nick Fischer watch as LLNL biologist Sean Gilmore loads a solution of NLP particles into an injection vial.



ENERGY AND ENVIRONMENT

Using science and technology to improve national energy security and surety, protect the environment, and understand and mitigate climate change

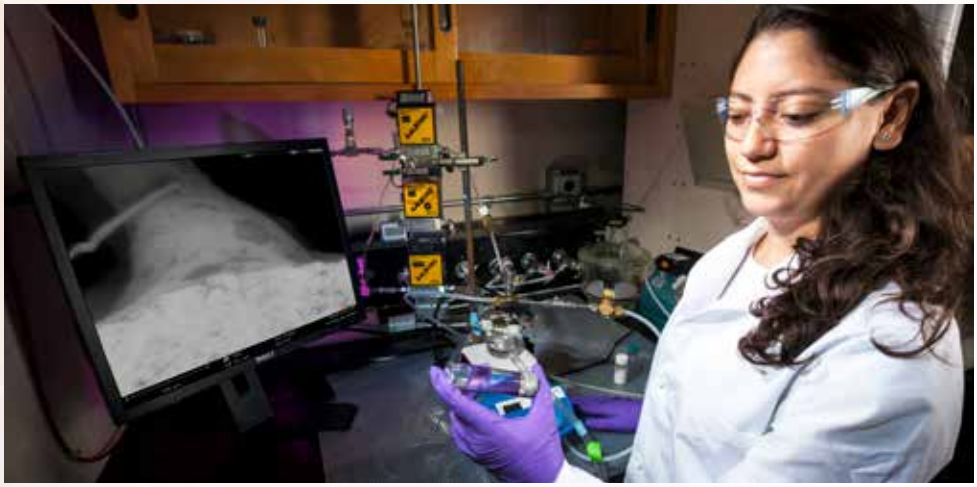
Laboratory researchers apply leading-edge capabilities to develop efficient and environmentally benign energy technologies and to investigate the processes that lead to climate change.

Simulating Earth's Complexity

After four years of development, version one of the Energy Exascale Earth System Model (E3SM) was unveiled to the scientific community. The continuing project's goal is to take advantage of supercomputers' increasing power to more reliably simulate aspects of earth system variability and project decadal changes that will critically impact the U.S. energy sector in the near future. E3SM represents the myriad interactions of atmosphere, oceans, land, and ice by solving approximations of physical, chemical, and biological governing equations. Continued enhancements to E3SM aim to better represent earth system processes and increase resolution. These efforts are proceeding in tandem with DOE's Exascale Computing Initiative to develop computer systems capable of carrying out a billion billion calculations per second. In a related new initiative, Laboratory scientists are collecting, archiving, and documenting climate data sets to support coordinated modeling efforts that study past, present, and future climates. Called the input data sets for model intercomparison projects (input4MIPs), the initiative aims to improve transparency, documentation, and consistency in the data sets used in climate simulations.

The Power of Microbes

Laboratory scientists in collaboration with Southern California Gas Company and Stanford University are using microbes and excess electricity produced by clean energy to convert carbon dioxide (CO_2) to methane (natural gas). The project aims to develop the prototype of a reactor to be used at biogas sources such as feed lots, farms, wastewater treatment plants, and landfills. Biogas is mostly methane, however it contains about 40 percent CO_2. The reactors would jointly reduce CO_2 emissions and store excess solar and wind energy as useable natural gas. Livermore's advances in 3D-printed carbon aerogel electrodes, to be used as efficient reactor materials, are key to the project's success. In a related effort, Laboratory scientists are working to improve the energy efficiency of copper-based catalysts for converting CO_2 into methane. The effort teams LLNL's supercomputing and advanced manufacturing resources with the laboratories of Silicon Valley-based Opus 12.



(left) The high-resolution E3SM earth system model simulates a strong hurricane (approaching the U.S. East Coast) to study how sea surface temperature evolves as the storm moves across the Atlantic. The resultant cold wake can intensify the next hurricane. (above) Postdoctoral researcher Maira Cerón Hernandez tests porous solid materials for containing a hot melt of highly caustic hydroxides that would capture CO_2 from power plant flue gas.

Loss of Arctic Sea Ice

A study by Laboratory researchers shows that over the next few decades the loss of ice in the Arctic Ocean could significantly affect California precipitation patterns. The study, part of a broad Livermore effort addressing climate change, used supercomputer simulations to identify a new link between the loss of Arctic sea ice and an atmospheric ridge in the North Pacific. Sea ice fluctuations can lead to convection changes over the tropical Pacific. These convection changes can in turn drive the formation of an atmospheric ridge in the North Pacific. The ridge steers wet tropical air masses away from California, thereby reducing rainfall in the state. Another study involving scientists from the Laboratory and five other organizations found that human influences significantly impact the magnitude of the seasonal temperature cycle at mid-latitude regions of Northern Hemisphere continents. Satellite temperature data are consistent with the model projections, indicating that this cycle is becoming stronger with more frigid winters and hotter summers due to human emissions of CO_2.

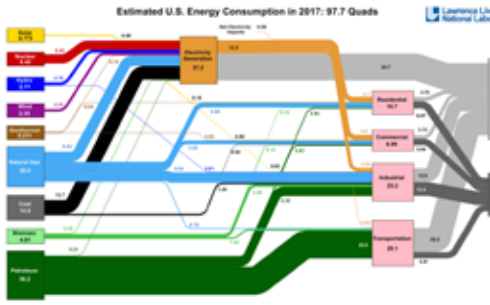
Partnerships with U.S. Industry

In FY 2018, DOE's Advanced Manufacturing Office announced two rounds of new awards in its High-Performance Computing for Manufacturing program (HPC4Mfg). The program leverages DOE's HPC resources to bolster U.S. manufacturing and clean-energy technologies. Laboratory researchers began work with Vitro Flat Glass to develop a neural network model for glass furnace operations, and LLNL initiated a project with KeraCel on manufacturing solid-state lithium-ion batteries. In addition, Lawrence Livermore and Argonne national laboratories are partnering with VAST Power Systems to optimize gas turbine combustors.

Since its inception in 2015, the HPC4Mfg program has been led by Lawrence Livermore in partnership with Oak Ridge and Lawrence Berkeley national laboratories. This year, DOE's Office of Fossil Energy launched a complementary new initiative to fund private–public partnerships aimed at using DOE HPC systems and expertise to discover, design, and scale up production of novel materials for use in challenging environments. This new HPC for Materials for Severe Environments program is also led by Livermore.

Optimizing Automobile Fuels

LLNL scientists are developing models of high-performance fuels to determine how they would work in advanced internal combustion engines. The research is part of a DOE national effort to provide industry with the scientific underpinnings needed to accelerate introduction of high-performance fuels and engines that reduce energy consumption, improve air quality, and lower drivers' costs. Called the Co-Optimization of Fuels and Engines, the initiative involves a collaboration between nine DOE national laboratories and industry in an effort to combine biofuels and combustion research and development. The Laboratory's combustion kinetics models are used, among other purposes, to identify optimum fuel blends from different chemical families.



Energy Flow Charts for Analysts and Decision Makers

Released by LLNL in FY 2018, the 2017 energy flow chart details the sources of energy production, how the U.S. is using energy, and how much of it is rejected into the environment. Each year since the mid-1970s, the Laboratory has published an expanding list of charts that illustrate the complex relationship between energy, water, and carbon (see *https://flowcharts.llnl.gov*). For this edition, LLNL worked with DOE and the National Energy Technology Laboratory to produce state-by-state energy and water flow charts for the year 2010 (the latest available data).

SCIENCE AND TECHNOLOGY

Expanding the boundaries of scientific knowledge and advancing the technological state of the art to solve problems of national and global importance

From the atom to the universe, Livermore studies natural phenomena at wide-ranging scales and develops technologies that enhance safety and security, preserve health, and improve quality of life. Science and technology research and development provide the tools for carrying out that mission.

Nanosatellites Ready to Fly

To demonstrate a new paradigm in the architecture of space systems, LLNL researchers have been developing innovative instruments, an adaptable platform, and operational principles for a type of nanosatellite called the CubeSat. Drawing on Livermore's expertise in precision optics, researchers designed a high-resolution monolithic optical telescope as small as 8.5 centimeters in diameter. In early 2018, the innovative, lightweight telescope, fabricated from a single piece of fused silica, was launched into low-Earth orbit as a demonstration system. The telescope produced excellent imagery of both stellar fields and ground targets. Potential CubeSat applications being considered for the low-cost imaging system include commercial and government Earth observations, space debris detection and tracking, and astronomical science observations. In addition, using a fleet of smaller satellites for a mission spreads the risk and provides "resiliency."

The Laboratory's latest CubeSat, called MiniCarb, is a collaboration between LLNL and NASA's Goddard Space Flight Center. MiniCarb uses the LLNL-developed CubeSat next-generation bus designed to standardize requirements and allow easier interchangeability of components. It will house an instrument for measuring the concentration of greenhouse gases in the Earth's atmosphere at specific altitudes of interest. MiniCarb is expected to be launched in 2019.

Plumbing Mysteries of the Brain

With its 100 billion neurons and 100 trillion interconnections, the brain presents a formidable challenge to scientific efforts aimed at understanding how it works and developing treatments for neural conditions. Laboratory scientists, working with the University of California at San Francisco and other partners, are using a flexible LLNL-developed neural probe containing a biocompatible microelectrode array to record brain activity in animals and humans over long durations. The hope is that lengthy recordings of brain activity will lead to better diagnosis and treatment for neurological disorders like Parkinson's disease, and neuropsychiatric conditions including depression and post-traumatic stress disorder. Research teams are using the probes in various ways, recording electrical signals

(left) Engineers prepare the latest CubeSat, called MiniCarb, for launch in 2019. (clockwise from lower left) Jenny Young (Genesis Engineering), Lance Simms (LLNL), Guru Ramu (Beacon Systems), and A.J. DiGregorio (Science Systems and Applications) install a NASA atmosphere monitoring instrument into the LLNL-designed CubeSat next-generation bus. (above) In LLNL's biomedical foundry clean room, a unique nationally recognized neural interface facility, postdoctoral researcher Allison Yorita fabricates components for Livermore Flexible Probes.

from single neurons and regions of the brain, and adapting the probes to measure the chemical signaling of neurotransmitters in the brain.

Game-Changing Concussion Study

A group of more than 40 researchers including LLNL scientists have identified evidence of early chronic traumatic encephalopathy (CTE) brain pathology after head impact even when signs of concussion were not present. The findings help explain why approximately 20 percent of athletes with CTE never suffered a diagnosed concussion. The study included the analysis of human brains from teenagers with recent head injury, animal experiments that re-created sports-related head impact and military-related blast exposure, and computational models of skull and brain injuries as they occur. The supercomputing simulations performed by Livermore researchers played a significant role in confirming that traumatic head motions from either blast or impact lead to CTE. Concussion is a separate phenomenon that results from shear stress when pressure is loaded through a focused point, as is often the case for impacts. Early indicators of CTE pathology not only persist long after injury but also spread through the brain, providing the best evidence to date that repeated head impact, not concussion, causes CTE.

Leadership in Scientific Computing

Researchers at Livermore continued to push the frontiers of computing power and speed. LLNL is fully engaged (including staff as members of the management team) in DOE's Exascale Computing Project, a collaboration between NNSA and the DOE Office of Science to develop and deliver exascale computers critical to national security, discovery, and economic competitiveness. In addition to research efforts for NNSA, Livermore participants are part of six teams awarded time on supercomputers at Argonne and Oak Ridge national laboratories as part of the Office of Science's Innovative and Novel Computational Impact on Theory and Experiment (INCITE) program. Livermore personnel were also prominent contributors to DOE's attention-grabbing news, displays, and presentations at the SC17 and SC18 supercomputing conferences.

LLNL is also advancing the application of high-performance computing through broad partnerships—notably in the area of bioscience and biotechnology. Livermore, the Frederick National Laboratory for Cancer Research, GlaxoSmithKline, and the University of California at San Francisco have joined forces in the ATOM (Accelerating Therapeutics for Opportunities in Medicine) consortium—using big data and supercomputers to transform cancer drug discovery. ATOM aims to reduce the time it takes for an identified drug target to become a clinical candidate from the usual six years to one year.

In addition, the Laboratory has partnered with the American Heart Association to speed up drug development for cardiovascular diseases using data science and simulation. Livermore also launched a supercomputing effort with two other DOE national laboratories in collaboration with the Transforming Research and Clinical Knowledge in Traumatic Brain Injury (TRACK-TBI) consortium to better understand TBI.

A Software Manager for Supercomputers

Spack (short for Supercomputer PACKage manager) is an LLNL-developed open-source package manager optimized for high-performance computing (HPC). It has become one of the most popular pieces of software LLNL has ever released to the GitHub open-source community. The tool automates installation and fine-tuning of simulations and libraries. Efficient packaging tools are critical in HPC environments because supercomputer simulations rely on hundreds of external software libraries. Spack is the go-to package manager for DOE laboratories' supercomputers and has become the official deployment tool for the Exascale Computing Project.

Laboratory physicist Jonathan DuBois examines a prototype quantum computing device with precisely controlled superconducting qubit circuitry, which is cooled to near absolute zero. At the frontier of high-performance computing, LLNL researchers are developing quantum computing components and striving to demonstrate a fully programmable quantum computing system.

Advanced Manufacturing Breakthroughs

Livermore-developed new advanced materials and manufacturing processes supported LLNL's national security missions and served to strengthen the economy and help create jobs. Along with its research partners, the Laboratory 3D printed a common form of marine-grade stainless steel, which is widely used in corrosive and high-stress environments such as aerospace, automobiles, chemical processing, and medical implants. The 3D-printed steel's strength and ductility were demonstrably superior to the traditional manufactured material. In addition, a Laboratory research team reported a breakthrough in 3D-printed complex graphene aerogels, which are lighter than air and stronger than steel. The process will be able to produce microarchitected structures with a complexity beyond anything produced so far. Graphene aerogel applications include advanced batteries, supercapacitors, and other energy technologies; water desalination; and chemicals processing. Livermore also advanced the 3D printing of nanoporous gold, which could revolutionize the design of electrochemical reactors to process clean fuels or convert carbon dioxide into useful products.

Developing new processes for advanced manufacturing is a continuing Laboratory focus. A research team demonstrated the use of machine learning to prevent defects in real time in 3D-printed metal parts. Another team discovered ways of improving the capabilities of a nanoscale 3D-printing method called two-photon lithography, which can print features one-hundredth the width of a human hair. Researchers also demonstrated how to use hologram-like 3D images to significantly accelerate "volumetric" printing of complex 3D parts, and how x-ray imaging can improve the quality of 3D printing.

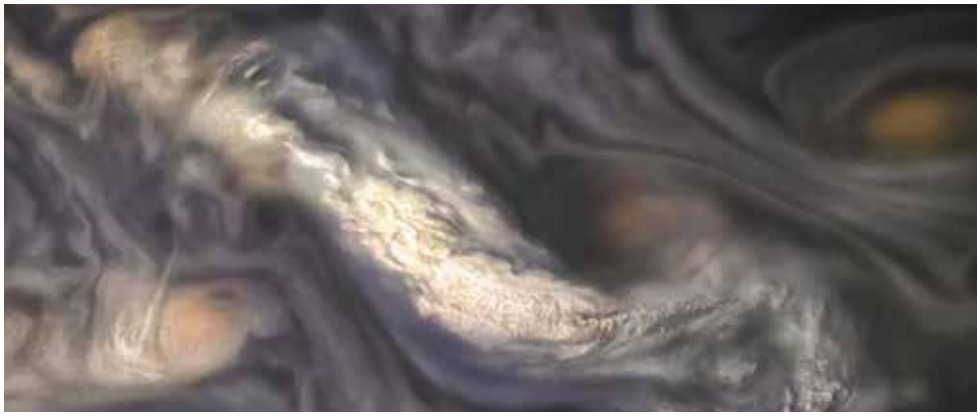
Quantum Computing's Revolutionary Potential

Quantum computing could be the next step in the evolution of faster, more powerful supercomputers. Laboratory researchers, working in a full-capability quantum computing laboratory and test bed facility, have built a prototype quantum computing device to explore the technology and determine how these machines might markedly advance DOE and NNSA missions. The team is also developing algorithms for solving quantum simulation problems on the prototype, which is a cylindrical metal box with a sapphire chip suspended within. The box is kept inside a refrigerated vacuum tube to preserve its superconductive state. Rather than digital ones and zeroes, these systems use the quantum states of atoms chilled to nearly absolute zero to carry out calculations. Quantum computers have the potential to solve some complex problems far more rapidly than traditional digital systems.

Other Planets Big and Small

Scientists have long theorized that water becomes superionic when heated to several thousand degrees at high pressure, similar to the conditions inside giant planets such as Uranus and Neptune. In superionic ice, liquid-like hydrogen ions move within a solid lattice of oxygen. Livermore and partners have published the first experimental evidence for superionic conduction in water ice at planetary interior conditions, verifying a 30-year-old prediction. Using shock compression, the team found predicted thermodynamic signatures including a high melting point, near 5,000 kelvin at 2 million atmospheres of pressure. Superionic ice may help explain the magnetic fields of Uranus and Neptune.

Livermore researchers' interests range widely in the science of nearby and exoplanets. Using computer simulations, they found that the bands of Jupiter, zonal flows of gas, are primarily a surface phenomenon—its strong magnetic fields suppress band formation deeper within the planet. Meanwhile, Livermore



A high-altitude cloud formation is surrounded by swirling patterns in the atmosphere of Jupiter's North North Temperate Belt region, one of Jupiter's many colorful, swirling cloud bands. Laboratory scientists and collaborators have theorized that Jupiter's magnetic field limits the depth to which these bands extend. Data collected by NASA's Juno orbiter suggest that the winds are "only" 3,000 kilometers deep—shallow compared to the radius of Jupiter.

cosmochemists have been studying Martian meteorites, fragments of rock from Mars knocked into space through collisions and recovered on Earth. Measurements of xenon gas trapped in these fragments reveal the evolution of the Martian climate and suggest little atmospheric change in 4 billion years, and that liquid water has not been abundant on its surface since the planet's first few hundred million years.

Discovering Properties of Materials

By coupling high-performance computer simulations with laboratory experiments, LLNL researchers are finding answers to some enduring mysteries of materials. Their results could lead to better materials for a variety of technologies. One team studied the process of how radiation causes defects in silicon, the basis of modern electronics, discovering that damage done to a material strongly depends on the density of cascades of radioactive particles colliding with it. The team's goal is to better understand the physical process to develop improved methods of protecting materials from radiation damage.

How the boundaries of grains that form a material affect its mechanical and chemical properties is a longstanding puzzle. Most materials are not uniform solids, but are made of tiny grains marked by boundaries consisting of various structures. Interested in how metals perform under extreme conditions, Livermore scientists have used powerful molecular dynamics simulations to study grain boundaries and discover, for example, why blacksmiths' methods for metal hardening work so well. LLNL researchers have developed a first-of-its kind tool that uses machine learning to sample the billions of possible boundary structures, find low-energy arrangements of atoms, and learn about their dynamic properties. The new tool for modeling grain boundaries has been successfully tested on selected materials. It will enable improved design of many energy technologies such as fuel cells and thermoelectrics, sensors, and laser optics.

Expanding Industrial Partnerships

LLNL is benefiting the U.S. economy with innovative technology and methods. In FY 2018, LLNL filed 144 new patents (including 43 provisional patents), obtained 105 new copyrights, and licensed 50 new technologies. Licensing income for the year totaled approximately $5.1 million. DOE's Technology Commercialization Fund is giving a valuable boost to Livermore's innovations. In 2018, LLNL researchers captured three large-scale cooperative development grants ($650,000 to $750,000), which directly connect Laboratory researchers with industrial partners, and two technology maturation grants (less than $150,000).

Petawatt Laser Ready for First Experiments

In June 2018, the L3-HAPLS advanced petawatt laser system was declared fully integrated and operational at the ELI Beamlines facility in the Czech Republic. A quantum jump in technology, the High-Repetition-Rate Advanced Petawatt Laser (HAPLS) was designed, developed, and constructed at LLNL in just three years. By focusing petawatt peak power at high intensity on targets, L3-HAPLS will create unparalleled access to research areas such as time-resolved radiography, astrophysics and other basic sciences, medical applications, and nondestructive evaluation of materials.

The cooperative development grants include one to advance the Earth Battery, a technology for storing renewable energy from intermittent sources until it is needed; a pioneering application for LLNL's microencapsulated sorbent to remove carbon dioxide from air (see p. 10); and a project to speed qualification of additively manufactured parts. The technology maturation grants include a fiber amplifier that could improve the stability of the nation's electrical grid and a method for rapidly manufacturing nanocrystal devices.

SAFE, SECURE, AND SUSTAINABLE OPERATIONS

Conducting safe, secure, and environmentally sound operations and modernizing the Laboratory's infrastructure to meet evolving mission needs

Committed to the highest level of operational performance, LLNL implements best practices in environment, safety, and health (ES&H), and security. Management systems support continuous improvement in work practices. Prudent risk management coupled with active measures to prevent accidents ensures the safety of employees and the public. Investments are targeted to modernize the Laboratory's infrastructure.

Attention to ES&H

Protecting workers and the environment and strengthening a strong safety culture continue to be primary focus areas for the Laboratory as high-visibility efforts continue on the W80-4 life-extension program, nuclear operations and waste disposal, work with hazardous materials, and a significant number of new construction and maintenance initiatives. In addition, overall positive ES&H operating results, performance metrics, and continuous improvement initiatives remain key facets of Livermore's Integrated Safety Management System. This year, the Laboratory achieved International Organization for Standardization 14001 Environmental Management System recertification and successfully completed the Occupational Health and Safety Management System 18001 surveillance audit with zero non-conformances identified. In FY 2018, the Centers for Disease Control and Prevention inspected the Select Agent Center for three-year registration renewal. The results were best ever with no findings. The inspectors complimented LLNL for maintaining an "excellent program" and being a "model entity." The Laboratory also garnered two DOE sustainability awards this past year.

LLNL continues to progress in implementing its new work planning and control process designed to ensure consistent Laboratory-wide practices, increase rigor and efficiency, and add value to work control documents. The goal is to convert all existing work control documents to the new system by the end of FY 2020. In addition, new initiatives such as "Take 5 for Safety and Security" videos continue to address injury risks including those relevant to traffic and construction safety; focusing on tasks; and slips, trips, and falls.

(left) The most visible site-improvement construction project in 2018 was the addition of a canopy over the kiosks at the Laboratory's East Avenue Gate. (above) James McConnell, NA-50 associate administrator of Safety, Infrastructure, and Operations, presented the Applied Materials and Engineering Area Plan team an Excellence Award for their innovative, cost-effective plans to consolidate and improve much-needed engineering capabilities.

Going Electric
In FY 2018, LLNL in collaboration with DOE launched a government-owned electric vehicle program, helping the Laboratory to reduce emissions and meet future sustainability goals. The Laboratory's fleet included 30 electric-powered sedans by the end of the year. In 2014, LLNL had launched a personal plug-in electric vehicle program for employees, who are billed for the electricity. Currently, 16 solar-powered level-II charging units are in use at various locations on site to support the growing use of electric vehicles.

Effective and Secure Operations

In FY 2018, operations at Livermore were well managed, with notable achievements in many areas in addition to ES&H. The Laboratory conducted efficient, effective business operations and financial management. Individual and team efforts achieved many notable successes in nuclear operations, emergency management, and information technology management. Security performance was audited by a 35-member DOE Office of Enterprise Assessments team, which reported only three findings, representing the lowest number of findings issued to any site in the last two years. Importantly, with a continuing focus on ensuring the safeguarding and security of DOE assets, Livermore experienced a more than 36 percent reduction in security incidents in FY 2018 compared to the prior year. In addition, fence relocations at the Laboratory reduced the Limited Area footprint by 30 percent, which lowers security costs and helps meet office space needs.

Progress Toward Site Sustainability

Environmentally responsible work practices are ensured by LLNL's Environmental Management System. These practices provide a systematic approach to identifying and reducing the environmental impact of Laboratory activities. The 2017 *Site Annual Environmental Report* (issued in October 2018) documents the Laboratory's compliance with environmental standards and monitoring results.

Overall, LLNL is on track to meet many of its sustainability goals. The 2025 goals for clean and renewable energy usage, reduction of fleet petroleum use, acquisition of zero-emission vehicles, electronic stewardship, and pollution prevention/waste reduction are on track or have already been achieved. However, goals in areas such as energy intensity (including associated greenhouse gas emissions) and water usage reduction are challenged by mission requirements. In particular, high-performance computing demands substantial energy and water for cooling. The many aging facilities onsite limit options for improving overall building energy efficiency.

Maintaining and Reinvesting in Infrastructure

In FY 2018, LLNL completed nearly 80 capital projects valued at more than $100 million—nearly matching the investment made over the prior four years combined. Construction began in June 2018 on the $34 million Expand Electrical Distribution System (EEDS) Project to install new 15-kilovolt power cables that will eliminate single-point failures to current facilities and support planned development. EEDS is first in a series of line-item projects planned for the Laboratory (see p. 18). Facilities and Infrastructure (F&I) revitalization is benefiting from the attention LLNL has placed on work safety and the development of enhanced tools for management of F&I and construction projects. Livermore made significant progress in rolling out the Enterprise Asset Management System and is at the forefront for implementing BUILDER, NNSA's infrastructure life-cycle modeling tool. In May 2018, the NNSA associate administrator of Safety, Infrastructure, and Operations presented LLNL personnel three NA-50 Excellence Awards—for injury-free construction in FY 2017, the Applied Materials and Engineering Area Plan (see p. 19), and creation of the Cooling and Heating Asset Management Program (CHAMP). Developed at LLNL, CHAMP is an innovative contract instrument for NNSA sites to effectively manage air-conditioning and heating equipment needs.

MANAGING FOR THE FUTURE

Positioning the Laboratory for continuing excellence in science and technology directed at important national missions

FY 2018 was a year focused on engaging with stakeholders and sponsors, providing technical leadership in key mission areas, and building for future successes.

Strategic Engagements and Initiatives

"What you're doing in a lot of different areas has the potential to change the world," remarked DOE Secretary Rick Perry to a Laboratory-wide audience in his first visit to the Laboratory in March 2018. Secretary Perry met with many staff members as he toured facilities and praised Laboratory employees for "making a difference in people's lives." Director William Goldstein and his management team also hosted visits by DOE Undersecretary for Nuclear Security and NNSA Administrator Lisa E. Gordon-Hagerty and many other distinguished guests during FY 2018. Extensive engagement by Laboratory programmatic and technical leaders is vital for staying informed about and helping to shape the evolving strategic landscape.

The nation benefits from LLNL's strong technical leadership in many facets of its national security mission. For example, Livermore is the Warhead Design Agency for the Conventional Prompt Strike Program, and the U.S. Air Force is proceeding with an LLNL-developed concept for an air-launched hypersonic strike weapon. LLNL's capabilities in directed-energy technologies are expected to play a key role in advancing missile defense, partnering with the Missile Defense Agency. Other examples of technical and programmatic leadership, such as in high-performance computing, are described elsewhere in this annual report.

New Facilities and Modernized Infrastructure

Construction of the Advanced Manufacturing Laboratory is completed (see box on p. 19). Many other projects are in preparation or underway as part of a more than $600 million facilities and infrastructure construction/acquisition portfolio for the Laboratory. Two of these include the $34 million Expand Electrical Distribution System project (see p. 17) and construction of a new Emergency Operations Center (EOC) at an estimated cost of $42 million. The EOC Conceptual Design Report was completed in March 2018 and the project is being readied for (Critical Decision) CD-1 review.

Two other major projects are vital to the success of Laboratory missions. First, in FY 2018, NNSA authorized the Laboratory to begin formal design for a construction project to prepare for the infrastructure demands over the next decade of two future

(left) LLNL Director William Goldstein, left, welcomes Department of Energy Secretary Rick Perry to the Laboratory. (above) A Data Science Institute summer program brought California State University at Long Beach student Kalvin Ogbuefi to the Laboratory. His essay about how his internship in the Machine Learning Group impacted his life won Ogbuefi a $1,000 grand prize scholarship from the university.

exascale systems. The first, El Capitan, will arrive as early as 2023. This machine is being developed by the CORAL consortium (see p. 5) working with U.S. industry in support of DOE's Exascale Computing Project. With a current cost range of $57 to $125 million, the Exascale Computing Facility Modernization project at Livermore will upgrade Building 453, where El Capitan will be housed, and construct infrastucture to provide necessary additional power and cooling. El Capitan will provide critically needed computing power for the W80-4 life-extension program and restarted work on a W78 replacement warhead.

The Stockpile Stewardship Program will also benefit from plans to modernize and consolidate engineering design, testing, and certification capabilities through the creation of an Applied Materials and Engineering campus within the main site's classified area. The five-year undertaking entails upgrades to several existing facilities and construction of two new laboratories and an office building.

Sustaining Workforce Excellence

An outstanding workforce is LLNL's principal strength. Staff members bring to their jobs impactful new ideas, work with integrity and zeal, and thrive in an inclusive work environment. LLNL ranks 24 out of 100 on Glassdoor's most recent "Best Places to Work US - Large" list—the top-ranked government/government contractor employer and top-ranked laboratory employer.

Accomplishments, activities, and initiatives highlight staff quality and the importance of recruiting and nurturing future technical and programmatic leaders. One new initiative is the creation of the Data Science Institute (DSI), which brings together myriad topics considered "data science" under one umbrella and strengthens LLNL's leadership in facets of artificial intelligence and machine learning. DSI serves as a hub for education, seminars, and collaborations and for building a workforce pipeline through programs such as the Data Science Summer Institute internship program. Similarly, the new Advanced Manufacturing Laboratory reaches out to academia and industry, and it helps workforce recruitment in another key research area for the Laboratory's future.

LLNS Board of Governors Activities

The LLNS Board of Governors and its committees provide oversight to the Laboratory and delve into issues crucial to mission and mission-support activities. External review committees (ERCs), panels of independent experts including Board members, held six meetings in FY 2018 to critically assess the quality of LLNL's technical workforce and the effectiveness of research efforts in meeting mission goals and future national needs. Their reports, which provided DOE/NNSA with an independent validation of work quality, consistently affirmed the mission relevance and high impact of Laboratory research. Functional Management Reviews (FMRs) chartered by the Board examine issues on an as-needed basis. Six FMRs were completed in FY 2018 in topical areas ranging from cybersecurity to work planning and control. Recommendations provided by Board committees, ERCs, and FMRs have led to substantive responsive actions.

The New Advanced Manufacturing Laboratory

In early FY 2019, doors are opening for research collaborations at LLNL's Advanced Manufacturing Laboratory (AML), sited at the Livermore Valley Open Campus. The new $10 million,14,000-square-foot facility houses leading-edge additive-manufacturing machines and equipment for supportive chemical work, materials characterization, and metrology. Laboratory scientists and engineers are welcoming academic and industrial partners for innovative collaborations at this one-of-a-kind facility. AML will advance the state of the art in manufacturing for the mutual benefit of U.S. economic competitiveness and LLNL missions.

COMMUNITY CONNECTIONS

Supporting local communities through science education and charitable giving

LLNL is a valued and contributing member of the community, providing science and technology outreach to a wide variety of students of all ages. Employees volunteer their time to enhance science, technology, engineering, and mathematics (STEM) education or advance community services through work with charitable and support agencies. Many organizations are supported through the Laboratory's Helping Others More Effectively—or HOME—campaign and the Lawrence Livermore National Security (LLNS), LLC, Community Gift Program.

Science That's "Fun"-damental

Each year more than 12,500 children at the fourth- and fifth-grade levels, along with their chaperones, are introduced to scientific concepts through LLNL's much-in-demand Fun With Science program. This program offers young minds a tour of the Laboratory's Discovery Center, followed by participation in hands-on experiments that introduce students to a scientific curriculum. Fun With Science is now a featured event at summer street fairs, science festivals, and other special events throughout the greater San Francisco Bay Area. In addition, educators attend LLNL's Teacher Research Academy to gain key skills they need to bring state-of-the-art science into their classrooms. During the year, the Laboratory hosted more than 50 teachers and 500 students across the nation—for internships and educational training.

A Flair for Fairs

LLNL promotes science and technology through various fairs and festivals. In November, the Laboratory took part in the seventh Bay Area Science Festival, which attracted more than 30,000 aspiring young scientists and their families to AT&T Park in San Francisco, California. In addition to participating in presentations of Fun With Science, visitors were given a virtual introduction to basic physics challenges, and kids hopped aboard special energy bikes to transform kinetic energy into power to run small household items and make lights glow.

The Laboratory also sponsors the annual Alameda County Science and Engineering Fair, held in March. More than 700 middle- and high-school students and 175 teachers from 18 school districts participated in the fair, earning awards and scholarships. In addition, 60 special awards were given by national and local government and industry sponsors. The science fair winners move on to the Intel International Science

(left) The Laboratory's "Art of Science" exhibit at the Bankhead Theater in downtown Livermore, California, offered a fascinating perspective of researchers' detailed technical work in a unique interplay between art and science. Captured by photographers, graphic artists, and state-of-the-art instruments, the larger-than-life to atomic-scale images were selected as much for their aesthetic quality as their scientific detail. (above) Fun With Science shows fascinated more than 100 underserved students attending STEM Day at LLNL in May 2018.

and Engineering Fair, the California State Science Fair, and the national Broadcom Masters competition.

Expanding Students' Horizons

Sponsored by LLNL, Expanding Your Horizons introduces STEM careers to middle- and high-school girls. The free events are held several times a year throughout the San Francisco Bay Area. They pair women scientists and engineers with students to conduct hands-on demonstrations of science and discuss career paths. The Laboratory also partners with Las Positas College for an annual Science and Engineering Seminar Series, in which LLNL researchers present "behind the scenes" perspectives of how multidisciplinary science really works. The seminars help to connect students to potential career paths.

Saturday Is Science Day

LLNL's Science on Saturday lecture series for middle- and high-school students plays to sold-out crowds every year. More than 6,000 people attended this season's 16 lectures held in the cities of Livermore, Tracy, and Oakland, California. This season the theme was "Marvelous Machines," with each topic highlighting LLNL's cutting-edge science and technology. Laboratory researchers paired with local science educators to discuss topics such as biologically inspired nanobots, flash imaging with x-ray lasers to show proteins in action, and laser–plasma accelerators to revolutionize medical procedures.

In addition, LLNL scientists challenge Hollywood's perspective on science and technology through the Science on Screen lecture series for middle-school to college-level students. It combines popular feature-length movies with prominent Laboratory researchers discussing the scientific viability of what's depicted in these classic, cult, and science fiction films. This year's series, again playing to sold-out audiences, looked at the evolution of computers, the ability to miniaturize, and advancing human health.

HOME Campaign and Community Gifts

In 2018, employees and LLNS raised more than $3.7 million in the HOME campaign. The annual charitable drive benefits community and nonprofit agencies in the Tri-Valley, San Joaquin Valley, and greater San Francisco Bay Area. Laboratory staff pledged more than $2.7 million and LLNS contributed $1 million in matching funds.

At an October ceremony at the LLNS office in the city of Livermore, California, LLNL Director and LLNS President William Goldstein presented checks totaling $100,000 to the 40 recipients of the 2018 LLNS Community Gift Program. These awards serve children in the Tri-Valley, East Bay, and Contra Costa and San Joaquin counties, with a focus on literacy, STEM education, and cultural arts. Other gifts focused on children, families, senior citizens, and individuals in need of assistance.

Lawrence Elementary School
In February 2018, Lawrence Elementary School was officially dedicated by Livermore Valley Joint Unified School District Superintendent Kelly Bowers, Livermore Mayor John Marchand, and LLNL Director William Goldstein (shown with students). Named in honor of the Laboratory and its contributions to the community, the school focuses on STEAM—science, technology, engineering, arts, and mathematics. The students voted to call themselves the "Lawrence Labs" and have as mascot a Labrador retriever.

WORKFORCE RECOGNITION

Acknowledging exceptional performance and expertise

Recognition from the scientific community and other stakeholders affirms the high quality of Livermore's work and innovative spirit. The awards listed on these pages showcase the efforts of the Laboratory's talented staff.

Early Career Research Award
Tammy Ma, a plasma physicist at LLNL, received a prestigious DOE Office of Science Early Career Research Program Award.

DOE Secretary's Achievement Award
Secretary of Energy Rick Perry honored chemist Bill McLean with a Secretary's Achievement Award in recognition of "pioneering technical contributions that have led to significant advancements in science-based stockpile stewardship."

NNSA Gold Awards
Livermore physicist George Anzelon was presented an NNSA Administrator's Distinguished Service Gold Award. The award recognized his work in nonproliferation and nuclear security.

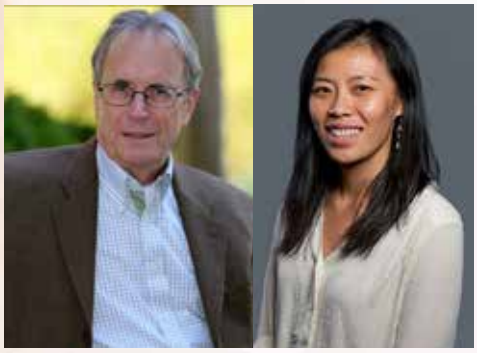
John Nasstrom, chief scientist of the National Atmospheric Release Advisory Center, also received an Administrator's Distinguished Service Gold Award for his service to U.S. national security.

NNSA Excellence Awards
NIF Operations Manager Bruno Van Wonterghem's contributions to NIF's important role in stockpile stewardship earned him an NNSA Defense Programs Exceptional Achievement Award. Four LLNL teams were also honored with Excellence awards.

Lifetime Achievement Award
Charles Orth was presented with the 2017 Albert Nelson Marquis Lifetime Achievement Award by Marquis Who's Who, a directory of short biographies of notable figures.

Defense Service Award
Livermore physicist Chris Cross earned an Outstanding Achievement Award from the Under Secretary of Defense for Research and Engineering for his work during a two-year assignment at the Department of Defense.

Professional Society Fellows and Seniors
Andrew MacPhee, Lorin Benedict, Patrice Turchi, and Nir Goldman were elected 2018 American Physical Society (APS) fellows. Nathan Barton, LLNL Director



(far left) In addition to external recognition of excellence, important accomplishments are honored with Laboratory Director's Excellence awards. Individual and team efforts are recognized in each of six categories (shown on commemorative coins) ranging from scientific publications to diversity and inclusion. (left) Chemist Bill McLean and physicist Tammy Ma both won high-level honors from DOE.

William Goldstein, and Robert Kirkwood were elected 2017 APS fellows.

Tayyab Suratwala and Jay Dawson were elected 2018 fellows of the Optical Society of America (OSA). Constantin Haefner and John Heebner were elected 2017 fellows of OSA.

William Pitz and LLNL retiree Charlie Westbrook were elected fellows of the Combustion Institute.

Computational mathematician Panayot Vassilevski was named a 2018 fellow of the Society for Industrial and Applied Mathematics.

Fady Najjar, a design physicist, was elected a fellow of the American Society of Mechanical Engineers.

Photonics engineer and staff scientist Corey Bennett has been elevated to senior status within the Institute of Electrical and Electronics Engineers.

Science and Technology Awards

Materials scientist Patrice Turchi has been selected as the recipient of the 2019 J. Willard Gibbs Phase Equilibria Award for outstanding contributions to the field of phase equilibria.

Computation Associate Director Bruce Hendrickson was presented with the George Cotter Award for Vision and Leadership in the field of data analytics at the Chesapeake Large-Scale Analytics Conference.

Magnetic fusion physicist Max Fenstermacher was awarded the 2018 John Dawson Award for Excellence in Plasma Physics Research from APS.

LLNL retiree Bruce Cohen was selected as the recipient of the 2018 Institute of Electrical and Electronics Engineers Nuclear and Plasma Sciences Society's Charles K. Birdsall Award.

Christopher Holcomb, a Livermore physicist stationed at General Atomics, was selected to receive Fusion Power Associates' 2017 Excellence in Fusion Engineering Award.

Scott McCall was chosen by the Minerals, Metals, and Materials Society (TMS) as recipient of the 2017 TMS Light Metals Award.

LLNL postdoctoral fellow David Weisz, who was mentored by Laboratory scientist Ian Hutcheon, has been named the first recipient of the Department of Homeland Security's new fellowship that honors Hutcheon.

Optimas Awards

The LLNL Strategic Human Resource Management directorate's International Services Office (Debbie Eaton, Linda Canaan, Michael Nguyen, Sheril Burke and Jorge Intal) received the 2018 Optimas Gold Award for managing change. The office handles services for more than 600 international Laboratory employees and visitors to LLNL each year.

The Nobel Prize

Former Laboratory staff scientist Donna Strickland and her mentor, French physicist Gérard Mourou, were named Nobel Prize laureates on October 2, 2018, for their work in developing chirped-pulse amplification to boost the power of ultrashort laser pulses up to the petawatt (quadrillion-watt) level. Strickland's Nobel Prize-winning research in Livermore's Laser Programs Directorate was instrumental in developing a series of groundbreaking short-pulse, high-energy laser systems. Strickland, who worked at LLNL in 1992, is only the third woman in history to win a Nobel Prize in physics.

An Optimas Silver Award from *Workforce* magazine was also presented to the Livermore Laboratory Employee Services Association for its visionary attention to work–life balance for employees.

Role Model Recognition

Marisol Gamboa was featured in the 2018 "New Mexico Women of STEM" (science, technology, engineering, and math) calendar. The calendar is produced by the New Mexico Supercomputing Challenge, in which Gamboa had once participated.

"Forty Under Forty"

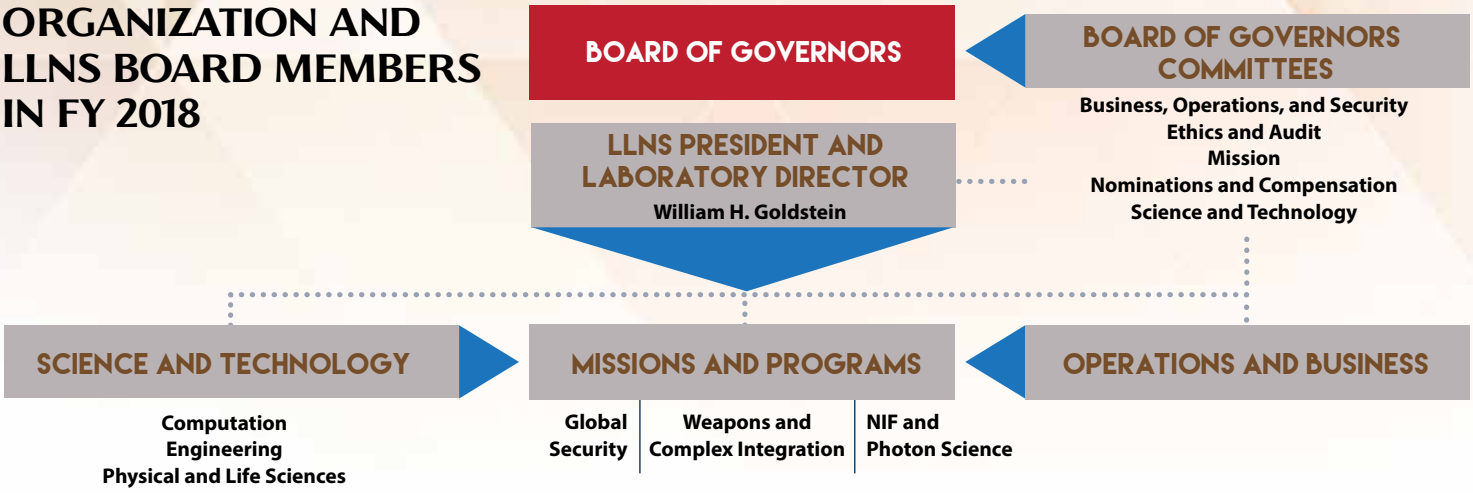
Five Laboratory researchers join *Diablo Magazine*'s annual "Forty Under Forty" list, which recognizes young professionals in the San Francisco East Bay who lead the charge in their fields. The five are: Sarah Baker, Louisa Pickworth, Marcus Worsley, Alicia Williams, and Leily Kiani.

LLNS President and LLNL Director William Goldstein poses with recipients at the annual LLNS Community Gift Program ceremony.

LAWRENCE LIVERMORE NATIONAL SECURITY, LLC

Overseeing management and operating the Laboratory for DOE/NNSA

ORGANIZATION AND LLNS BOARD MEMBERS IN FY 2018



LLNS is a limited liability company managed by members Bechtel National, Inc.; the University of California; BWXT Government Group, Inc.; and the URS Division of AECOM. Battelle Memorial Institute also participates with LLNS as a teaming subcontractor. Cutting-edge science is enhanced through the expertise of the University of California and its 10 campuses and LLNS' affiliation with the Texas A&M University system.

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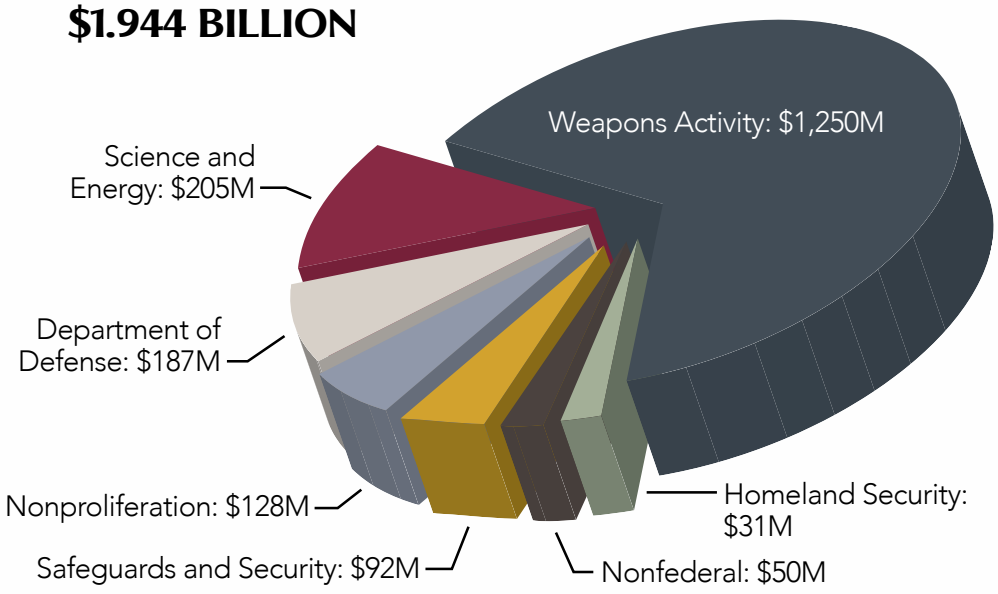
John Nuckolls Honored with Foster Medal

Seven laboratory directors and a U.S. Air Force general were among the many colleagues and friends who paid tribute to John Nuckolls as he was presented the John S. Foster Jr. Medal on November 8, 2018. Nuckolls was recognized for his significant contributions to national security as an innovative intellectual leader, the driving force behind the quest for inertial confinement fusion, and the seventh Laboratory director. As director, Nuckolls envisioned the risks that the nation would face post-Cold War and positioned LLNL to be responsive to the challenge. He is the fourth recipient of the Foster Medal, established by LLNS in honor of the award's namesake.

LLNL FY 2018 ACTUAL COSTS: $1.944 BILLION



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